

Rule 1.26

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Client Ref.: AL-02-15R2  
Our ref: 0751-10171-US/final/Vincent

What is claimed is:

1        1. A method for I/Q imbalance calibration of a  
2 transmitter, comprising the steps of:  
3        initializing parameters  $A_p$ ,  $B_p$  and  $\gamma_p$ ;  
4        estimating a loop delay factor  $L$ ;  
5        generating a test signal  $x[n]=x(n \cdot T_s)$ , wherein  $x(t)=e^{j\omega_T t}$   
6            and  $\omega_T$  is a preset radian frequency and  $T_s$  is  
7            sampling interval;  
8        generating a compensated signal  $x_{com}[n]$  by compensating  
9            the test signal  $x[n]$  according to a first  
10            function with parameters  $A_p$ ,  $B_p$  and  $\gamma_p$ ;  
11        converting the compensated signal  $x_{com}[n]$  to an analog  
12            signal  $x_{com}(t)$ ;  
13        applying I/Q modulation to the analog signal  $x_{com}(t)$  and  
14            outputting a modulated signal  $x_{mod}(t)$ ;  
15        obtaining a characteristic signal  $x_c(t)$  of the  
16            modulated signal  $x_{mod}(t)$ ;  
17        obtaining a sampled characteristic signal  $x_s[n]$  by  
18            sampling the characteristic signal  $x_c(t)$  and  
19            obtaining statistics  $U_1$  and  $U_2$  of the sampled  
20            characteristic signal  $x_s[n]$ , where  $U_1$  and  $U_2$  are  
21            values indicative of the frequency response of  
22             $x_c(t)$  at radian frequency  $\omega_T$  and  $2\omega_T$ ,  
23            respectively; and  
24        updating the parameters  $A_p$ ,  $B_p$  and  $\gamma_p$  respectively by  
25            one of the second functions, the loop delay  
26            factor  $L$ , the statistics  $U_1$  and  $U_2$ , and the  
27            current values of the parameters  $A_p$ ,  $B_p$  and  $\gamma_p$ .

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1        2. The method as claimed in claim 1, wherein the step  
2 of estimating the loop delay factor further comprises the  
3 steps of:

4        generating a test signal  $x'[n] = \cos(\omega_T n T_s) + \gamma_T$  which is a  
5 discrete-time signal and  $\gamma_T$  is a predetermined  
6 number;

7        converting the test signal  $x'[n]$  to an analog signal  
8  $x'(t)$ ;

9        applying I/Q modulation to the analog signal  $x'(t)$  and  
10        outputting a modulated signal  $x_{\text{mod}}(t)$ ;

11        obtaining a characteristic signal  $x_c(t)$  of the modulated  
12        signal  $x_{\text{mod}}(t)$ ;

13        obtaining a sampled characteristic signal  $x_s[n]$  by  
14        sampling the characteristic signal  $x_c(t)$  and  
15        obtaining a statistics  $V$  of the sampled  
16        characteristic signal  $x_s[n]$ , where  $V$  is a value  
17        indicative of the frequency response of  $x_c(t)$  at  
18        radian frequency  $\omega_T$ ; and

19        estimating the loop delay factor  $L$  based on the  
20        statistics  $V$ .

1        3. The method as claimed in claim 2, wherein the  
2 statistics  $V$  is obtained by taking FFT of the sampled  
3 characteristic signal  $x_s[n]$ .

1        4. The method as claimed in claim 3, wherein the  
2 estimated loop delay factor  $L$  is  $V/|V|$ .

1        5. The method as claimed in claim 1, wherein the  
2 first function is  $x_{\text{com}}[n] = A_p \cdot x[n] + B_p \cdot x[n] - \gamma_p$ .

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1        6. The method as claimed in claim 1, wherein the  
2 statistics  $U_1$  and  $U_2$  are obtained by taking FFT of the  
3 sampled characteristic signal  $x_s[n]$ .

1        7. The method as claimed in claim 1, wherein the  
2 parameters  $A_p$ ,  $B_p$  and  $\gamma_p$  are updated by the steps of:

3        computing the updated  $A_p$  based on the current  $A_p$  and  $B_p$ ,  
4                the loop delay factor  $L$ , and the statistic  $U_2$ ;

5        computing the updated  $B_p$  based on the current  $A_p$  and  $B_p$ ,  
6                the loop delay factor  $L$ , and the statistic  $U_2$ ;

7                and

8        computing the updated  $\gamma_p$  based on the current  $\gamma_p$ , the  
9                loop delay factor  $L$ , and the statistic  $U_1$ .

1        8. The method as claimed in claim 1, wherein the  
2 second functions for updating the parameters  $A_p$ ,  $B_p$  and  $\gamma_p$   
3 are:

4         $A_p' = A_p - \mu \cdot B_p \cdot U_2^* \cdot L \cdot L$ ;

5         $B_p' = B_p - \mu \cdot A_p \cdot U_2 \cdot (L \cdot L)^*$ ; and

6         $\gamma_p' = \gamma_p + \mu \cdot U_1 \cdot L$ ;

7        where  $A_p'$ ,  $B_p'$  and  $\gamma_p'$  are the updated values,  $A_p$ ,  $B_p$  and  
8                 $\gamma_p$  are the current values, and  $\mu$  is a preset step  
9                size parameter.

1        <sup>9</sup>  
~~10.~~ The method as claimed in claim 1, wherein the  
2 characteristic signal is derived by taking the square of an  
3 envelope of the modulated signal.

1        <sup>10</sup>  
~~11.~~ The method as claimed in claim 2, wherein the  
2 characteristic signal is derived by taking the square of an  
3 envelope of the modulated signal.

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1 ~~12.~~ An apparatus for I/Q imbalance calibration in a  
2 transmitter comprising:

3 a discrete-time signal generator generating a first  
4 test signal  $x_1[n] = \cos(\omega_T n T_s) + \gamma_T$ , where  $\omega_T$  is a preset  
5 radian frequency,  $T_s$  is a predetermined sampling  
6 interval, and  $\gamma_T$  is a predetermined number, in an  
7 estimation phase, and generating a second test  
8 signal  $x_2[n] = e^{j\omega_T n T_s}$  in a calibration phase which  
9 follows the estimation phase;

10 a correction module receiving the test signal from the  
11 signal generator, compensating the test signal  
12 according to a first function with parameters  $A_p$ ,  
13  $B_p$  and  $\gamma_p$  to produce a compensated signal;

14 a first and second D/A converter converting the  
15 compensated signal to an analog signal, wherein  
16 the first D/A converter converts the real part of  
17 the compensated signal to the real part of the  
18 analog signal, and the second D/A converter  
19 converts the imaginary part of the compensated  
20 signal to the imaginary part of the analog  
21 signal;

22 a modulator applying I/Q modulation to the analog  
23 signal, and outputting a modulated signal;

24 a detector obtaining a characteristic signal of the  
25 modulated signal;

26 an A/D converter converting the characteristic signal  
27 to a sampled characteristic signal; and

28 a processor implementing the steps of:

29 initializing the parameters  $A_p$ ,  $B_p$  and  $\gamma_p$ ;

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30. obtaining a statistic  $V$  based on the sampled  
31. characteristic signal in the estimation  
32. phase, where  $V$  is a value indicative of the  
33. frequency response of  $x_c(t)$  at radian  
34. frequency  $\omega_T$ ;  
35. estimating a loop delay factor  $L$  based on the  
36. statistic  $V$  in the estimation phase;  
37. obtaining statistics  $U_1$  and  $U_2$  based on the  
38. sampled characteristic signal in the  
39. calibration phase, where  $U_1$  and  $U_2$  are values  
40. indicative of the frequency response of  
41.  $x_c(t)$  at radian frequency  $\omega_T$  and  $2\omega_T$ ,  
42. respectively; and  
43. updating the parameters  $A_p$ ,  $B_p$  and  $\gamma_p$  based on the  
44. loop delay factor  $L$ , the statistics  $U_1$  and  
45.  $U_2$ , and the current values of the parameters  
46.  $A_p$ ,  $B_p$  and  $\gamma_p$  in the calibration phase.

1 <sup>12</sup>~~12~~. The apparatus as claimed in claim <sup>11</sup>~~12~~, wherein the  
2 statistics  $V$  are obtained by taking FFT of the sampled  
3 characteristic signal in the estimation phase.

1 <sup>13</sup>~~13~~. The apparatus as claimed in claim <sup>11</sup>~~12~~, wherein the  
2 loop delay factor  $L$  is  $V/|V|$ .

1 <sup>14</sup>~~14~~. The apparatus as claimed in claim <sup>11</sup>~~12~~, wherein the  
2 first function is  $x_{com}[n] = A_p \cdot x[n] + B_p \cdot x'[n] - \gamma_p$ , where  $x[n]$  and  
3  $x_{com}[n]$  denote the test signal and the compensated signal,  
4 respectively, and  $x[n] = x_1[n]$  in the estimation phase,  $x[n] =$   
5  $x_2[n]$  in the calibration phase.

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1 <sup>15</sup>~~16~~. The apparatus as claimed in claim <sup>11</sup>~~12~~, wherein the  
2 statistics  $U_1$  and  $U_2$  are obtained by taking FFT of the  
3 sampled characteristic signal in the calibration phase.

1 <sup>16</sup>~~17~~. The apparatus as claimed in claim <sup>11</sup>~~12~~, wherein the  
2 processor updates the parameters  $A_p$ ,  $B_p$  and  $\gamma_p$  by the steps  
3 of:

4 computing the updated  $A_p$  based on the current  $A_p$  and  $B_p$ ,  
5 the loop delay factor  $L$ , and the statistic  $U_2$ ;

6 computing the updated  $B_p$  based on the current  $A_p$  and  $B_p$ ,  
7 the loop delay factor  $L$ , and the statistic  $U_2$ ;  
8 and

9 computing the updated  $\gamma_p$  based on the current  $\gamma_p$ , the  
10 loop delay factor  $L$ , and the statistic  $U_1$ .

1 <sup>17</sup>~~18~~. The apparatus as claimed in claim <sup>16</sup>~~17~~, wherein the  
2 processor updates the parameters  $A_p$ ,  $B_p$  and  $\gamma_p$  by the  
3 equations::

4  $A_p' = A_p - \mu \cdot B_p \cdot U_2^* \cdot L \cdot L$  ;

5  $B_p' = B_p - \mu \cdot A_p \cdot U_2 \cdot (L \cdot L)^*$  ; and

6  $\gamma_p' = \gamma_p + \mu \cdot U_1 \cdot L$

7 where  $A_p'$ ,  $B_p'$  and  $\gamma_p'$  are the updated values,  $A_p$ ,  $B_p$  and  
8  $\gamma_p$  are the current values, and  $\mu$  is a preset step  
9 size parameter.

1 <sup>18</sup>~~19~~. The apparatus as claimed in claim <sup>11</sup>~~12~~, wherein the  
2 characteristic signal is derived by taking the square of an  
3 envelope of the modulated signal.